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LABORATORY EXPERIMENT

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A Model Approach to the Electrochemical Cell: An Inquiry Activity

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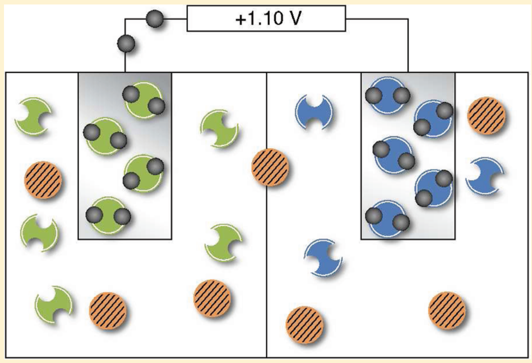
Supporting Information

ABSTRACT: In an attempt to address some student misconceptions in electrochemistry, this guided-inquiry laboratory was devised to give students an opportunity to use a manipulative that simulates the particulate-level activity within an electrochemical cell, in addition to using an actual electrochemical cell. Students are led through a review of expected prior knowledge relating to oxidation and reduction half-reactions. Then, the students examine the macroscopic level by constructing and using an electrochemical cell. Finally, students use the manipulative and make connections between the two levels through class discussion. The misconceptions involve the movement of electrons and ions through solution and the salt bridge, the resulting charges of the half-cells, and the charge sign given to the anode and cathode on electrochemical and electrolytic cells. Additionally, the activity covers oxidation and reduction reactions in electrochemical cells and provides practice drawing and labeling parts of an electrochemical cell. Results, pre- and post-testing and student comments, indicate that this laboratory facilitates students' understanding of electrochemical cells.



KEYWORDS: First-Year Undergraduate/General, High School/Introductory Chemistry, Laboratory Instruction, Physical Chemistry, Hands-On Learning/Manipulatives, Inquiry-Based/Discovery Learning, Misconceptions/Discrepant Events, Electrochemistry, Electrolytic/Galvanic Cells/Potentials, Oxidation/Reduction

Chemistry instruction has historically included a lecture presenting facts, a laboratory with finite expectations, and practice in mathematical application. There is an abundance of research that encourages instructors to modify the approach from dissemination of information to students to guiding students to a conceptual understanding of chemistry through exploration of the macroscopic, particulate, and symbolic representations of chemistry concepts.[1,2] Teaching in the latter way places new requirements on the instructor. First, the instructors must be aware of the misconceptions that students have about specific chemistry topics. Bodner[3] encourages chemistry instructors to research the topics and survey student knowledge before modifying instruction. Teaching methodologies must evolve to include multiple representations. Yezierski and Birk[4] show that animations are a useful vehicle to help students connect the macroscopic, particulate, and symbolic representations to support conceptual understanding. However, the use of animations is just one way to modify the instructional strategies. Second, instructors must continuously identify student misconceptions and find intervention strategies that provide students experience at the macroscopic, particulate, and symbolic levels while encouraging student reflection.[5]

The nature of student misconceptions about electricity[6] and electrochemistry[7] is well-known and there is evidence that chemistry textbooks and instructors are responsible for many student misconceptions related to electrochemistry.[8] Huddle, White, and Rogers[9] found that instructors tend to use everyday language that can have multiple meanings within the context of science and that many statements made by these instructors can be misinterpreted by students. Thus, they designed a lecture demonstration model of an electrochemical cell[9] to address the following student misconceptions:

- Current is believed to involve movement of electrons, even in solution and through the salt bridge.
- In an electrochemical cell, anions and cations move either until their concentration in both half-cells is equal or until one half-cell is strongly negatively charged and the other is strongly positively charged.
- Many students interpret a negative electrode to imply that the electrode is negatively charged. Generally, students lack understanding of the significance of the signs of the anode and the cathode and what happens to these signs when changing from an electrochemical to an electrolytic cell.

Unfortunately, the Huddle et al. model is not practical for use with small groups of students because of the expense and time involved in building several models. Thus, a modified activity was created with the goals of being inexpensive, portable, and flexible. This activity captures the important features of the Huddle model, while making it suitable in terms of size and cost, for hands-on use by high school students. In the modified activity,

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every student group is provided the opportunity to move electrons, atoms, and ions through a paper model of a voltaic cell.

OVERVIEW OF THE LABORATORY

As previously stated, students will be more successful in understanding chemistry concepts if instructors address the macroscopic, particulate, and symbolic levels of chemistry. At the heart of this laboratory is the modified version of the Huddle demonstration model. The model developed by Huddle addresses the particulate level of an electrochemical cell well when used as a demonstration and this model has been modified to allow teams of students an opportunity to manipulate the model in small groups as part of a larger guided-inquiry laboratory. The activity allows students to actively discover the relationships between the macroscopic, particulate, and symbolic representations themselves as opposed to passively being shown the relationships. In the laboratory, students build a voltaic cell, and while that cell is running, they manipulate the electrons, atoms, and ions in the paper model of the cell. The relationship between particulate-level model and macroscopic-level cell are examined by facilitation questions and small-group discussion, which leads to the discovery, or at least a deeper understanding, of the electrochemical concepts. Students relate the oxidation and reduction half-reactions occurring in the actual cell (macroscopic level) to the paper model (particulate level) and then to the chemical equations (symbolic level) they wrote. The use of the paper model allows the students to visualize where the electron transfer takes place and the electron and ion movement occurring in the actual voltaic cell. The model is not used by the instructor as part of a demonstration or lecture, but instead it is used by the students to construct their understanding of the electrochemical cell they are using in the laboratory. In traditional lecture and verification laboratories, students rely heavily on the instructor for help in understanding. In this laboratory, the role of the instructor is that of coach or facilitator. The new facilitating role allows for students to work through the problems and questions that arise, thus, allowing them to gain a deeper understanding.[10]

The laboratory is intended for use as the introductory exercise to an electrochemistry unit. Oxidation and reduction half-reactions should be addressed before beginning the laboratory. The laboratory provides for a common experience that may be referred to throughout the remainder of the unit. For example, as written, the activity does not address the common misconception about the electrode sign change that occurs when a cell is switched from an electrochemical cell to an electrolytic cell. The activity could easily be modified to address this misconception.

HAZARDS

The 0.10 and 1.0 M solutions of copper(II) sulfate can be mildly toxic by ingestion and an irritant to skin, eyes, and mucous membranes. The 1.0 M zinc sulfate solution is classified as a mild body tissue irritant. Avoid body tissue contact for both. The students should wear proper laboratory attire when they are working with the electrochemical cell.

DETAILS OF THE LABORATORY

The laboratory is divided into two sections, each with an experiment and observations. In the first section, students place a piece of zinc wire into a solution of copper(II) sulfate. They observe the reaction and write the oxidation and reduction half-reactions. Through the assigned questions and instructor-led discussion, students are directed to follow the transfer of electrons as the reaction proceeds. This is intended to be a review of prior knowledge as well as an opportunity for the instructor to identify any misconceptions before leading into the topic of electrochemical cells.

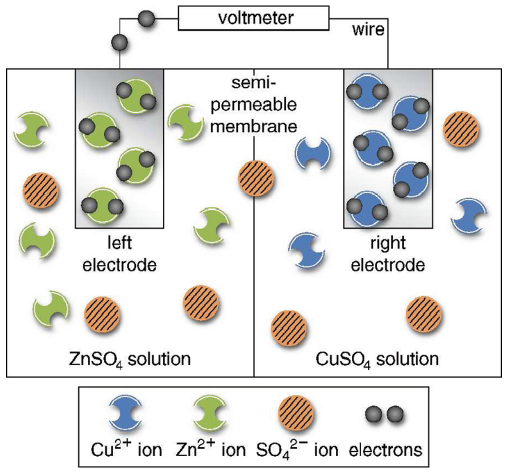

Figure 1. Voltaic cell model kit.

In the second section, students make predictions, run an experiment, and make observations (part A), and use a paper model to further their understanding (part B). Finally, the students collect data to verify their predictions (part C). In part A, students construct an electrochemical cell using solutions of copper(II) sulfate and zinc sulfate, strips of copper and zinc wire, a porous cup, and a voltmeter. Prior to constructing this cell, students are asked to reflect on their prior knowledge and the initial reaction viewed at the start of the laboratory to predict how the mass of the zinc and copper electrodes will change during the use of the cell.

While the electrochemical cell is running, students move to part B. Students are directed to set up the voltaic cell model kit as shown in Figure 1 and to manipulate the ions and electrons through the cell to simulate the movement of these particles during the reaction occurring within the electrochemical cell they have set up in part A. An important aspect of the activity is for the instructor to circulate and observe use of the model and listen to conversations surrounding the simulation to catch and address misconceptions. In part C, students disconnect the macroscopic electrochemical cell and verify the mass of the electrodes to check their predictions.

An opportunity, through assigned questions, for reflection of how the macroscopic and particulate levels are related is provided as the activity concludes. Group discussion is encouraged to support reflection, and to help identify and address any remaining misconceptions about electrochemistry. During this discussion the instructor's role is to listen carefully and probe for any misconceptions that still need to be addressed.

RESULTS AND DISCUSSION

The paper model is easy to duplicate for instructors and it is easy to make enough copies for small groups to work together (see the Supporting Information). The limitations of the model are discussed within the framework of the activity. Students can easily see the lack of water molecules in the paper model and the small number of ions and electrons. However, students can see that no electrons pass into the solutions. Students comment that they can see the gain and loss of mass of the electrodes in the model just as they can see it in the actual electrochemical cell. They can also see that there must be a transfer of ions across the semipermeable membrane (or through the salt bridge) to avoid a buildup of charge.

To test the efficacy of the laboratory, 34 advanced placement chemistry students completed an assessment 3 days prior to performing the laboratory. The same 22 question assessment was completed 8 days after the completion of the electrochemistry unit. The questions were selected from test bank questions on the *Journal of Chemical Education* Web site.[11] The questions were standard electrochemistry questions: students were given a picture of an electrochemical cell and asked a series of questions about the cell.

The data were normally distributed so that a paired samples t test could be used. The scores on the post-test (mean = 72.86%, SD = 12.50) were higher than the pretest (mean = 28.88%, SD = 11.29, $t(33) = -20.512$, $p < 0.001$, $r = 0.96$). Although the use of the same questions for the pre- and post-test might cause the post scores to be inflated due to recognition, the magnitude of the difference and the effect size (r) indicates that students' understanding was increased. Other efficacy data comes from student comments:

- I am glad that we created the cell in the lab, so that we could see the voltage created and really see the reaction happen. But, the model helped me to visualize what was happening with the electrons and ions.
- I liked that the model was simple. It really helped me understand the actual process of electrochemistry much better than observing a battery in the lab. It showed the paths of the ions and electrons very well.

During the use of the model, students were overheard explaining the movement of the ions and electrons as they demonstrated the model for others within their small groups that were having difficulty with the material, providing more evidence that the students were constructing their own understanding of the workings of an electrochemical cell.

ASSOCIATED CONTENT

Supporting Information

Detailed student and instructor guides. This material is available via the Internet at http://pubs.acs.org.

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(12) The Energizer activity along with other inquiry-based activities created by instructors involved in the Target Inquiry Program at Grand Valley State University may be accessed at http://www.gvsu.edu/targetinquiry/index.cfm?action=tidocuments.home. A password is required to obtain materials. This initial registration is for data collection only. The site provides free instructor and student guides, facilitation notes, student misconceptions addressed by each laboratory, and help with setup and assessment questions.